CHARACTERIZATION OF A SILICON NITRIDE PLASMA ETCH: SELECTIVITIES AND UNIFORMITY

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ABSTRACT

A silicon nitride plasma etch process with good nitride-to-oxide selectivity has been developed at RIT. Two fluorine etchant gases, CF4 and SF6, were characterized for etch rate and selectivities, and the effects of oxygen and hydrogen loading determined. It was found that the SF6 etch provided a selectivity of 6:1 (with a nitride etch rate of about 700 A/minute) when no loading was applied. The 3:1 CF4:02 etch demonstrated a comparable nitride etch rate, but with a poorer selectivity (about 5:2). The uniformity of the Tegal 700 plasma etching system was determined to be the limiting factor during the etch.

INTRODUCTION

Silicon nitride (Si_3N_4) is a CVD film commonly used in the VLSI industry as a masking material for the localized oxidation of silicon (LOCOS). The nitride prevents the diffusion of oxygen to the silicon surface and any subsequent oxide growth. LOCOS has become the most common isolation technique because it reduces surface topography considerably with a minimum amount of process difficulty.

A simplified LOCOS isolation process is shown in Figure 1. To protect the underlying silicon substrate from the nitride etch, a thin pad oxide (A) is grown before the nitride deposition to serve as an etch-stop. If the silicon substrate is exposed to the etch, surface defects and poor thermal oxides may result. To decrease the effect of the bird's beak encroachment (B) and allow for a higher packing density of devices, it has become necessary to use thinner pad oxides under the nitride [1]. This dictates the need for a high nitride-to-oxide selectivity to protect the underlying silicon.

The chemistry involved with the plasma etching of nitrides and oxides is now discussed. Freon 14 (CF_4) will be used as an example, but the etching mechanisms of SF_6 plasmas are analogous. The dissociation of the fluorocarbon CF_4 can be summarized by the following equation,

$$e + CF_4 \longrightarrow CF_3 + F + e \qquad (1)$$

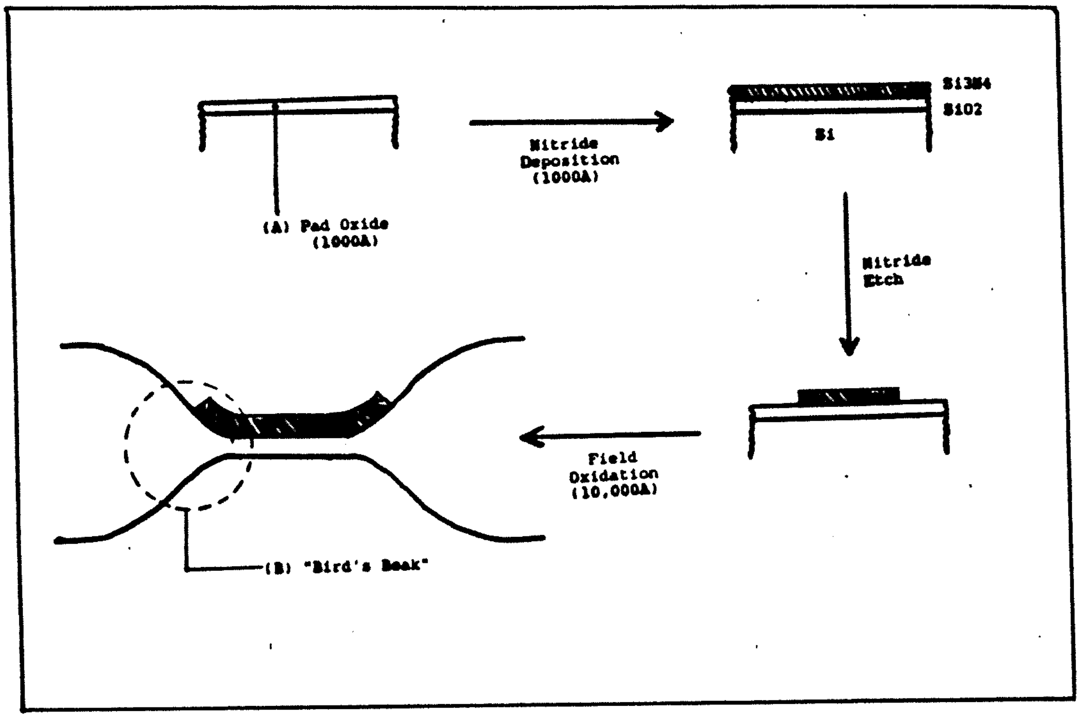


Figure 1: Schematic representation of a simplified LOCOS process and the resulting "Bird's Beak" encroachment.

where e represents an electron and F is the free fluorine radical. At the electron energies encountered in typical glow discharges, the above reaction does not proceed directly but by the following 2-step mechanism [2].

$$e + CF_4 \longrightarrow CF_3 + F^- \quad \text{:dissociative attachment}$$

$$e + F^- \longrightarrow F + 2e \quad \text{:(rapid) detachment}$$

It has been shown that the F radical is the primary etchant of silicon, while the CF_3 radical is most responsible for the etching of SiO_2 and Si_3N_4 [3]. The basic chemistries involved in the etching of oxide and nitride can be described by the following unbalanced equations. These are the chemical reactions which occur when oxide and nitride are exposed to a CF_4 plasma.

$$CF_3 + SiO_2 \longrightarrow SiF_4 + CO, CO_2 \qquad (2)$$

$$CF_3 + Si_3N_4 \longrightarrow SiF_4 + CFN \qquad (3)$$

All the products are volatile allowing both reactions to proceed readily. The problem of acquiring a high nitride-to-oxide selectivity results from the similarity of the two etch chemistries.

The etch rates of silicon based materials have been found to depend on the carbon-to-fluorine (C/F) ratio of a fluorocarbon plasma [4]. To adjust the C/F ratio of a plasma, fluorine promoters or scavengers are added to the process chemistry to increase or decrease the fluorine radical concentration. Efficient scavengers of F atoms in a plasma include H_2, CH_4, and C_2H_4. The addition of the hydrogen ties up some of the available F producing HF and decreasing the F concentration. CHF_3 has also been used to decrease the F concentration in an etch. Oxygen is the most common F promoter, reacting with the carbon to produce CO or CO_2 and increasing the F concentration. The C/F ratio is often used to describe the composition of a fluorocarbon plasma. The addition of a scavenger to a CF_4 plasma increases the C/F ratio, while oxygen loading results in a decrease in the C/F ratio.

Since a fluorine-deficient plasma provides a high oxide-to-silicon selectivity, a high C/F ratio plasma is often used to etch oxides and nitrides in case the substrate happens to be exposed during the etch. However, if too much fluorine is removed, carbon deposits or polymers may form on the wafer surface preventing further etching [2]. For this reason, most oxide and nitride etches operate close to the etching/polymerization borderline, creating difficult process control.

The new NMOS and CMOS technologies presently being introduced into the RIT microelectronics facility will utilize a LOCOS process for the initial field oxidation. Therefore, the optimization of a nitride etch process with high nitride-to-oxide selectivity has become a necessity.

EXPERIMENT

A Tegal 700 series plasma etcher (a single wafer etcher with a shower-head gas delivery system) was utilized for this experiment. Gas flows were controlled using two MKS mass flow controllers and an MKS 247B Digital Readout. From previous experiments, the acceptable total gas flow for the Tegal 700 was found to be about 15 sccm [5]. This flow was used for each of the gases and gas mixtures to determine the etch uniformity and selectivities.

Several wafers were prepared with alternating lines of nitride and oxide, cross-hatched with lines of KTI-820 positive photoresist as shown in Figure 2. This allowed for the etch rates of all three materials to be determined simultaneously. The initial thicknesses were determined by standard Nanospec measurement programs and found to be approximately 1000A, 900A, and 1.2um for the nitride, oxide and resist, respectively. Table 1 gives the etch parameters used throughout the experiment.

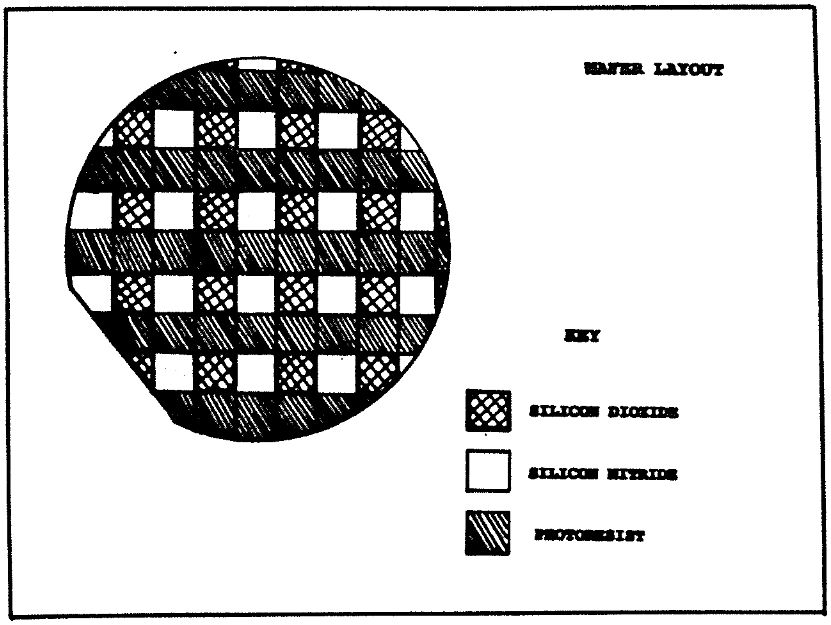


Figure 2: Wafer layout used for the experiment.

Table 1: Etch parameters.	
Total Gas Flow...........	15 sccm
Chamber Pressure.........	650 mT
RF Power.................	125 W
Etch Time................	30 sec

The uniformity of the etch was determined by Nanospec measurement of each material at each point on the wafer before and after a CF_4 etch. To measure the nitride-to-oxide selectivity of various gas combinations, five points were measured on each wafer before and after etch and an average etch rate calculated. The gases and gas mixtures used were CF_4, CF_4/O_2 (2:1,3:1), CF_4/CHF_3 (2:1,3:1), SF_6, SF_6/O_2 (2:1,3:1), and SF_6/CHF_3 (3:1).

RESULTS/DISCUSSION

Figure 3 shows a wafer map of etch rates across a wafer and the calculated uniformity [8]. The poor uniformity (52% variation across the wafer) is most likely due to chamber leaks or an uneven gas delivery. The lack of uniformity necessitates the need for a nitride etch with good nitride-to-oxide selectivity and should be improved to ensure process stability.

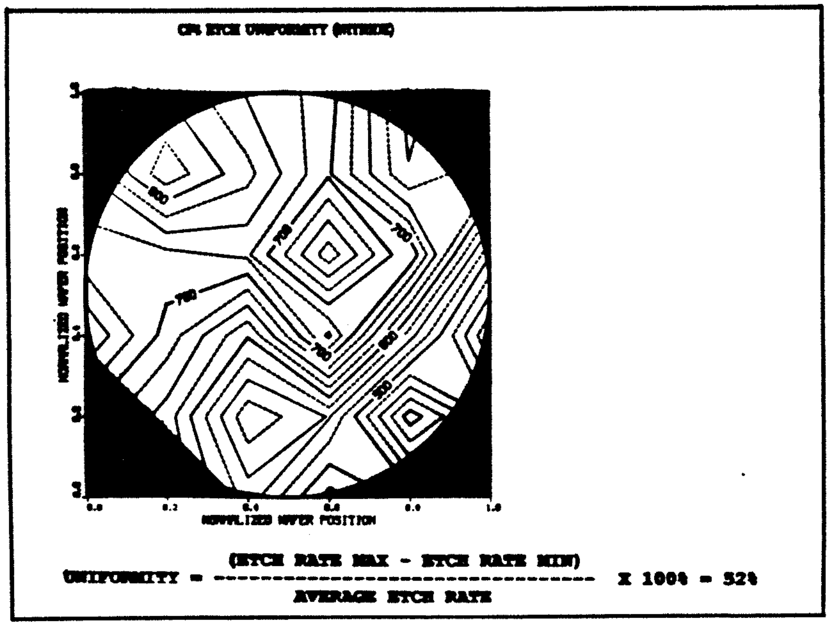


Figure 3: Wafer map of etch rates measured across a wafer.

Average etch rates for straight CF4 and SF6 plasmas were determined as given in Table 2. From these rates, the nitride-to-oxide selectivities were calculated by the following equation.

$$\text{Nitride/Oxide Selectivity} = \frac{\text{Nitride Etch Rate}}{\text{Oxide Etch Rate}} \qquad (4)$$

It was determined that the SF6 etch provided better selectivity than the CF4 etch with comparable etch rates. The selectivity of the SF6 plasma was almost 3 times better than the CF4. The following table provides the etch rates and selectivities obtained.

Table 2: Etch Rates and Selectivities for CF4 and SF6

Parameter	CF4	SF6
Nitride Etch Rate (A/min)	645	730
Oxide Etch Rate (A/min)	313	125
Nitride/Oxide Selectivity	2.1	5.9

The average etch rates and selectivities for each combination of gases were also determined. Figures 4 and 5 summarize the resulting etch rates and selectivities.

Figure 4: CF4 Etch Rates vs Loading

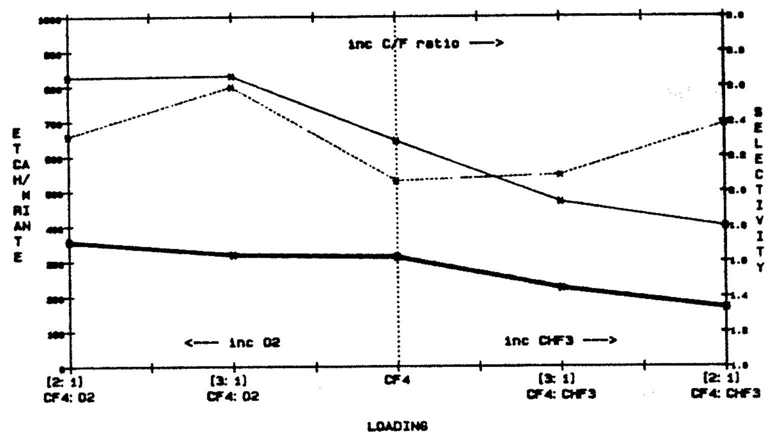
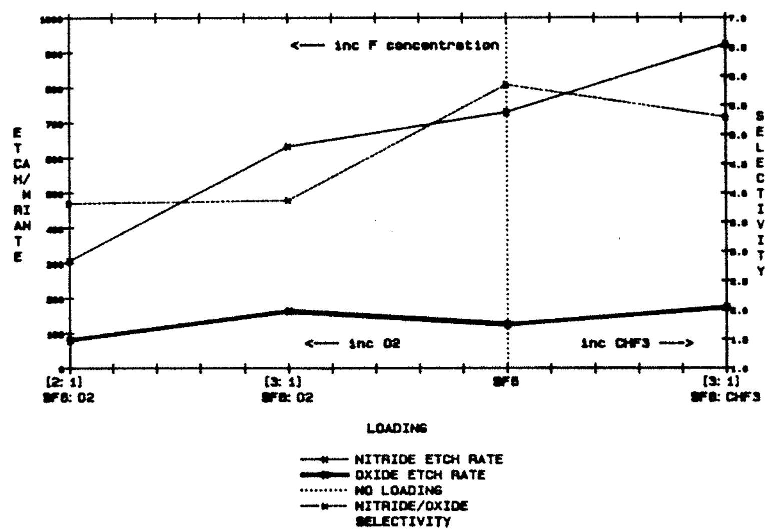


Figure 5: SF6 Etch Rates vs Loading



Increasing the C/F ratio decreased both the nitride and oxide etch rates for the CF4 etch chemistry as expected. This is probably due to polymer formation on the wafer's surface. The nitride-to-oxide selectivity was observed to increase slightly with the addition of CHF3 to the process, but the best selectivity (about 5:2) occurred with a [3:1] CF4/O2 mixture.

An interesting result was observed when CHF3 was added to the SF6 etch in a 3:1 mixture. Although the total concentration of available fluorine in the plasma should have decreased, both nitride and oxide etch rates were found to have increased substantially. This result is difficult to explain without an extensive amount of additional materials and research, but clearly warrants further investigation. The use of spectral monitoring of the plasma or a residual gas analyzer would be beneficial in further understanding the mechanisms involved.

CONCLUSIONS

This experiment provided valuable information on the limitations of the Tegal 700 plasma etcher presently being used at RIT. A uniformity variation of 52% across the wafer is extremely high and dictates the need for etch chemistries with high selectivities to the underlying substrates. The SF6 etch was found to provide a better nitride-to-oxide selectivity (6:1) than the CF4 etch (5:2). Straight SF6 was found to provide the best selectivity of all the gases and gas combinations analyzed. This result has been substantiated by previous experiments where superior nitride-to-oxide selectivity has been observed with SF6 chemistries [1,7].

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